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TECHNICAL NOTE

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PERFORMANCE OF ELECTRICAL-RESISTANCE STRAIN

GAGES AT CRYOGENIC TEMPERATURES

By Albert Kaufman

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GAGES AT CRYOGENIC TEMPERATURES

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SUMMARY

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Six types of commercial foil strain gages were investigated to determine whether they could be used in experimental stress analyses of space-vehicle structures at cryogenic temperatures. The effects of low temperatures on the gage factors were studied by mounting gages on constant-strain beams and loading them to strains of up to ± 2000 microinches per inch with a strain-gage calibrator immersed in a cryogenic bath. These tests were conducted at room temperature and liquid-nitrogen (139° R) and liquid-hydrogen (36° R) temperatures. Hysteresis, creep, zero-drift effects, and linearity of the data were also studied in these tests. [Electric Testing]

The more promising types of strain gages, as determined from the calibrator tests, were mounted on beta titanium tensile specimens and tested to higher strains of from 7500 to 13,000 microinches per inch in liquid hydrogen. Resistance measurements were made on the different gages at room temperature and dry-ice (350° R), liquid-nitrogen, liquid-hydrogen, and liquid-helium (7° R) temperatures.

Two types of Nichrome V gages that were tested showed almost no change in gage factor down to liquid-hydrogen temperature. The resistances of the Nichrome V gages decreased about 3 percent from room temperature to 7° R (liquid-helium temperature). A strain gage of stabilized Armour alloy D showed a resistance decrease of less than 0.50 percent over this same temperature range. The gage factor in liquid hydrogen, as compared with the room-temperature factor, decreased about 4 percent for positive strains and increased $1\frac{1}{2}$ percent for negative strains. Creep, zero-drift, and hysteresis effects were small for these strain gages. The stabilized Armour D gages were tested to 8000 microinches per inch in liquid hydrogen before some failures occurred. Some of the Nichrome V gages were tested to 13,000 microinches per inch in liquid hydrogen without failure of either the gage or the cement bond. None of the foil gages exhibited any change in room-temperature resistance or strain sensitivity after immersion in the cryogenic fluids. [Techniques for applying and testing gages are discussed]

INTRODUCTION

Space vehicles containing a propellant such as liquid hydrogen, with a

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boiling point of 36° R at 1 atmosphere, are subjected to highly complex stress distributions due to a combination of thermal, pressurization, inertial, and bending effects. Complete analytical determination of these stress distributions is not always possible, and a strain transducer is, therefore, required that will work satisfactorily at liquid-hydrogen temperatures. The primary transducer used in conventional experimental stress analysis has been the electrical-resistance strain gage, and therefore its characteristics were reviewed to determine its suitability at cryogenic temperatures.

Ideally, an electrical-resistance strain gage for use at cryogenic temperatures would exhibit (1) no change in strain sensitivity from the room-temperature value, (2) no change in resistance from the room-temperature value, (3) an output that would be linear up to strain levels of primary engineering concern (approx. 10,000 μ in./in.), and (4) no creep or hysteresis effects. Because no specific gage could be expected to meet all these requirements, a program was initiated to survey the various available gages and to determine which, if any, would have performance characteristics that would be adequate for most stress analysis problems.

Six types of foil gages were investigated; these included noncompensated gages and self-temperature-compensated gages. The performance characteristics investigated and reported herein are change in strain sensitivity, change in resistance, response to high strains, creep, zero drift, and hysteresis. Some preliminary results of this investigation were presented in reference 1. The present report covers more detailed testing methods and additional gage types and presents results from larger samples of individual gage types.

APPARATUS

Strain-Gage Calibrator

In order to determine the change in strain sensitivity with temperature, gages were mounted on cantilever-beam specimens and tested in the strain-gage calibrator shown in figure 1. The specimens were $7\frac{1}{2}$ inches long and 0.15 inch thick and were fabricated from 2014-T6 aluminum alloy. The width of the beams was tapered linearly to provide a test area for gage mounting in which the strain was a constant for a given beam deflection. In general, three pairs of gages were mounted back to back on a specimen, the exact number depending on the gage size.

The strain-gage calibrator was designed to impose deflections on the beam specimens by the rotation of an eccentric circular cam that moved a block to which one end of the specimens was pinned. The block was free to float axially within the frame of the calibrator; this eliminated any strain component from an axial movement of the specimen as might occur through a temperature change or an axial component of the load. The opposite end of the specimens was fixed. The calibrator provided for testing two beam specimens at one time. An indexed disk was attached to the cam to ensure accurate repetition of intermediate deflection points.

There were 16 positions on the indexed disk. These imposed deflections in 1/8-inch increments from 0 to +1/2 inch to -1/2 inch and back to the 0 position as the disk was turned 1 complete revolution. A deflection of 1/2 inch corresponded to a strain of ± 2000 microinches per inch, the sign depending on which side of the beam the gage was located and on the direction of deflection. The calibrator was locked by a spring-loaded tapered pin going through the tapered holes of the indexed disk.

The calibrator was placed in a cryostat in the facility described in reference 2. The indexed disk and the locking device were manually operated through shafts coming out of the cryostat. Temperatures were measured with a platinum resistance thermometer attached to the calibrator.

Strain Measurement

For each strain gage on the specimens, a dummy gage was also immersed in the cryostat. The dummy gage was of the same type and was mounted on the same material as the active gage. Teflon-insulated 26-gage copper wires were attached to copper tabs that were, in turn, connected with copper wire to each gage terminal on the calibrator-beam specimens and to the dummy terminals. A multiwire circuit was used to eliminate possible errors due to temperature-induced resistance changes in the lead wires.

An automatic, multichannel strain-gage recorder, having an accuracy of 1 percent, was used to measure the strain-gage outputs. The maximum current put through the gages was about 15 milliamperes.

Six types of foil strain gages were tested with the calibrator. These included foil gages of Advance, Karma, modified Karma, Nichrome V (from two sources), stabilized Armour D (three gage sizes), and Nichrome V - platinum (temperature compensating). In addition, calibrator tests were conducted on Evanohm weldable gages and semiconductor gages. All the weldable gages failed in the welds, and all the semiconductor gages behaved erratically in these tests. It was not felt that sufficient work had been done to give a fair evaluation of these gages, and, therefore, they are not discussed further. Compensating gages were not used with the Nichrome V - platinum gages. Instead, ballast resistors, as recommended by the manufacturer for gages mounted on aluminum, were put in series with the platinum elements outside the cryostat.

Tensile Testing

Strain gages were also mounted and tested on tensile specimens of beta titanium alloy 13V-11Cr-3Al-Ti. This alloy was chosen because, in liquid hydrogen, the linear portion of the stress-strain curve extends to very high strains. Thus, the more promising strain gages, as determined from the calibrator tests at strains up to approximately 2000 microinches per inch, could be tested on the tensile specimens to strains of as much as 13,000 microinches per inch. These specimens were 3/8 inch wide and 1/8 inch thick and had a test section 2 inches long.

The wiring system and recording apparatus described previously were also used for the tensile tests. Strain gages were mounted back to back on each side of the specimen for each test. A snap-on linear, variable-differential transformer-type extensometer of 1 inch gage length was mounted over one strain gage in most of the tensile tests and connected to a chart recorder. This extensometer had previously been calibrated while immersed in liquid hydrogen by means of a micrometer-driven calibration device. The tensile tests were performed with a 12,000-pound-capacity tensile machine and the cryostat described in reference 3. Only stabilized Armour D and Nichrome V foil gages were studied in the high-strain tensile tests.

PROCEDURE

Mounting of Strain Gages

As reported in reference 1, a number of cements including cyanoacrylate, silicone rubber, Bakelite, and epoxy were investigated for mounting strain gages for use at cryogenic temperatures. The effects of variations in curing cycles and thicknesses of coatings, as well as Mylar and cellophane tape backings, were tested. The best results were attained with GA-5 epoxy cement.

The mounting procedure for the foil gages was begun by lightly abrading the surface of the material with an air-abrasive unit and then spraying a 1-mil pre-coat over the area with an airbrush. This coat was allowed to set at room temperature for about 4 hours, after which a light mounting coat was sprayed over it. If the strain gage had a stripable backing, it was embedded in the cement without the backing and clamped to the specimen with silicone rubber pads with a pressure of about 5 pounds per square inch. All the foil gages except the Advance and the Nichrome V - platinum gages were stripable. In the case of those that were not, the gage with its backing was embedded in the cement and clamped. The cement was cured at a temperature of 175° F for 16 hours. After the curing cycle, the lead wires were soldered to the gage. There was difficulty in obtaining good solder joints with the stabilized Armour D gages, and in some cases leads were welded to the terminals. An overcoat of cement, not exceeding 1 mil, was then sprayed on, and the curing cycle was repeated. It was necessary to maintain a total mount thickness no greater than 2 mils to minimize cracking or crazing of the cement under the combination of high strain and low temperature. Thinner coats were likely to result in electrical grounds.

Beam Calibrator Tests

Before a test was started, electric current was passed through the gages overnight; experience showed that this practice minimized zero drift. Three runs were then made at room temperature. A run consisted of recording the gage outputs for each of the 16 deflection positions of the calibrator; the indexing disk was always turned in the same direction. When the room-temperature runs were completed, liquid nitrogen was added. After the temperature had stabilized, three more runs were made.

This same procedure was repeated for the liquid-hydrogen tests. After the liquid hydrogen had boiled off and the calibrator was completely dry, three more room-temperature runs were performed to determine any change in the room-temperature strain sensitivities of the gages due to immersion in the cryogenic baths. The calibrator tests were used to determine the changes in the strain sensitivities at the various temperatures; tensile tests were used to determine the gage factors. In addition to these runs, each specimen was held at both zero and maximum deflections for 1/2 hour during the cryogenic tests; strain-gage outputs were recorded every 5 minutes to check zero-drift and creep effects.

Analysis of Calibrator Data

The strain data were entered into an IBM 7090 computer program. With this program, the reading for each deflection position was first corrected for the zero drift between the beginning and the end of a revolution of the calibrator indexing disk. Each intermediate deflection position was credited with a proportionate amount of the drift. The linearity of the data from zero to maximum or minimum deflection was checked, and the equations of the best straight lines were calculated by the method of least mean squares. Positive and negative strain data were treated separately because there was a significant difference in the slope of the lines through the data in some cases. The equations for the hysteresis lines through the unloading data points ($\pm 3/8$ in. to 0 deflection) were also determined in the same way.

The slopes of the lines for all the runs, at a given cryogenic temperature, were averaged and compared with the averaged slopes from the preceding room-temperature runs. The ratio of these slopes for a particular gage is identical to the ratio of the gage factor at the cryogenic temperature to that at room temperature.

Tensile Tests

The strain sensitivity factor given by the manufacturer was checked by loading tensile specimens, with gages mounted on them, over a strain range of several thousand microinches per inch at room temperature and comparing the strain-gage output to the extensometer results.

Tests were then performed with the tensile specimens immersed in a cryostat full of liquid hydrogen. One type of test consisted of continuously loading the specimen and taking readings at certain load intervals until either the strain gages failed or the specimen failed. The degree to which the data departed from linearity was a measure of the effects of creep and zero drift.

In another type of tensile test, the zero drift was taken into account by cycling the load back to a preload of 100 pounds and subtracting the gage output at the test load from the average of the gage outputs of the preceding and following preloads. The loads were continuously increased using this cycling method until failure of either gage or specimen occurred. Extensometers were

mounted on most of the specimens tested.

Resistance Measurements

Resistance measurements on samples of all the strain-gage types used were made at room temperature and dry-ice (350° R), liquid-nitrogen (139° R), liquid-hydrogen (36° R), and liquid-helium (7° R) temperatures. Two gages of each type were checked. Except for the Evanohm weldable gage, all were mounted on blocks of 2014-T6 aluminum alloy. In addition, resistance measurements were made on Nichrome V gages mounted on beta titanium and type 304 stainless steel. The room-temperature resistances were checked before and after immersion in the cryogenic baths to determine whether there was any permanent change due to exposure to these temperatures. For these resistance measurements, gage current was about 1 milliampere.

RESULTS AND DISCUSSION

Resistance Measurements

In figure 2 the results of measuring the resistances at specific temperatures from room temperature to that of liquid helium (7° R) are shown for a number of foil gages mounted on 2014-T6. The data are plotted as a resistance ratio (ratio of resistance at the test temperature to that at room temperature) as a function of the temperature of each of the cryogenic baths in which the gages were immersed.

The most stable gage material was stabilized Armour D, which showed a resistance change of less than 0.50 percent over the whole temperature range and less than 0.25 percent from room to liquid-hydrogen temperature. Next to stabilized Armour D, the Evanohm weldable gage, which was unmounted, showed the best resistance stability from room temperature to 36° R. A recheck, however, of the room-temperature resistance after immersion in liquid helium showed a resistance change of about 10 percent. For this reason, no data point is shown at 7° R for the Evanohm gage. This was the only case in which a gage exhibited a permanent change in resistance at room temperature after a cooling cycle.

It should be noted in figure 2 that all the curves except the one for the Advance gages reverse themselves at the extremely low temperatures and show an increase in resistance between liquid-hydrogen or liquid-nitrogen and liquid-helium temperatures.

Although the resistance change from room to liquid-hydrogen temperature was within a few percent for most of the gages, the equivalent apparent strains are quite large. For example, the stabilized Armour D gages would show an apparent strain of about 400 microinches per inch, which would require correction if thermally induced strains were being measured across this temperature range. The next most resistance-stable material, Evanohm, would show an apparent strain of 4700 microinches per inch and the worst, Advance, would show 25,000 micro-inches per inch upon being cooled from room temperature to 36° R. In the liquid-

hydrogen region, the slope of the Advance curve is so steep that a variation of 1° R would cause a change of 200 microinches per inch.

Resistance-ratio curves are shown in figure 3 for Nichrome V gages mounted on three different materials. The total resistance change from room to liquid-helium temperature was about 3 percent. The maximum difference in resistance in liquid hydrogen among the three curves is less than 1 percent; however, the differences in apparent strain are considerable. For a Nichrome V gage mounted on titanium, the apparent strain in cooling from room temperature to 36° R is about 11,000 microinches per inch as compared with over 14,000 microinches per inch for a gage mounted on aluminum. Thus, when strain gages are used to measure thermal stresses, careful consideration must be given to the effect of the different temperature coefficients of expansion of the different alloys on which the gages are mounted. At 7° R, the stainless steel and titanium curves in figure 3 do not show the recovery that the aluminum curve does. This indicates that the upward hook of the curves around 7° R in figure 2 for gages mounted on aluminum was due to a change in the ratio of the thermal coefficients of expansion of the gage materials to the thermal coefficient of expansion of the aluminum.

Strain Sensitivity Measurements

The results of the beam calibrator tests of strain sensitivity of gages in liquid nitrogen and liquid hydrogen are summarized in table I. Listed in the table are the number of gages of each type that were tested and the average maximum and minimum strain sensitivity ratios that were measured for both tensile and compressive strains. (The strain sensitivity ratio is the ratio of the gage factor at the cryogenic temperature to the gage factor at room temperature.) No effect on the room-temperature strain sensitivity was found when these gages were immersed in the cryogenic fluids.

The table lists two different Nichrome V gages obtained from different sources. Since the results for these were virtually identical, they were combined in the table. Also listed are three gage-element sizes for the stabilized Armour D type, all obtained from the same source. No significant trend due to gage size was apparent; therefore, the results for all these gages were also combined. The results are summarized in the bar graphs of figure 4 for liquid nitrogen and hydrogen. The Nichrome V gages showed virtually no change in strain sensitivity in either cryogenic fluid. Stabilized Armour D showed the next smallest change in strain sensitivity from room to liquid-hydrogen temperature.

There are a number of unusual features about the results shown for the stabilized Armour D gages in figure 4. One of these was the relatively large difference in strain sensitivity change between tensile and compressive strains. The average strain sensitivity ratio for the stabilized Armour D gages varied from 0.961 in tension to 1.012 in compression in liquid nitrogen and from 0.963 in tension to 1.016 in compression in liquid hydrogen. Only the Advance gage in liquid hydrogen showed a distinct difference; in this case, part of the difference may have been due to the large variation in strain sensitivity in liquid hydrogen (see table I). The other gages showed only small variations between

the tensile and compressive strain sensitivity ratios, and these were within the possible range of experimental error.

In figure 5(a) the calibrator loading data, corrected for zero drift, are plotted for a typical stabilized Armour D gage at liquid-hydrogen and room temperatures. Figure 5(a) indicates that, for liquid hydrogen, the data were linear over the whole deflection range. In contrast, at room temperature, the slopes were different for each quadrant. Thus, it appears that the gage factors for stabilized Armour D gages are the same in tension and compression at liquid-hydrogen temperature but different at room temperature. It will also be noted that the four room-temperature data points from 0 to 3/8 inch deflection were fairly linear, whereas the 1/2 inch deflection point was off the line. Nonlinearity effects such as this occurred for each stabilized Armour D gage of every size and lot in every run at room temperature; it is believed that they were not caused by any experimental error. The linearity for both positive and negative strains improved as the temperature decreased although, in some cases, there was still some nonlinearity at the liquid-hydrogen temperature. This is the main reason why the variation in strain sensitivity ratio for the stabilized Armour D gages (table I) is much less in liquid hydrogen than in liquid nitrogen.

In figure 5(b) the results of testing a typical Nichrome V gage in the calibrator are shown. These data were also corrected for zero drift. The linearity of the data was excellent from the maximum to the minimum deflection, and the lines for room and liquid-hydrogen temperature were virtually identical.

Creep and Zero-Drift Effects

The drift in liquid hydrogen of stabilized Armour D and Nichrome V gages of different sizes, held for a period of 1/2 hour at zero and maximum deflection of the calibrator-beam specimen, is plotted in figure 6. Because some of the gages were in tension and some in compression at the maximum deflection, only the magnitude, and not the sign of the drift, was taken into account. At a nominal strain of zero, the maximum variation for all the gages was 8 microinches per inch. At strains of ± 2000 microinches per inch, the maximum drift was less than 16 microinches per inch. Thus, the zero-drift and creep effects can be considered negligible. It should be noted that, with the stabilized Armour D gage, for both strain levels, the drift increased as the gage-element size decreased. This is probably caused by the smaller gages having to dissipate more current per unit area. Since areas of the gage elements of the Nichrome V gages were about the same, this effect was not evident for them.

Hysteresis Effect

In figure 7 the hysteresis effect, to 2000 microinches per inch in liquid hydrogen, is shown for the various gages as a bar graph of the ratio of the loading to the unloading strains from the calibrator tests. The hysteresis effect was 2 percent or less for both tensile and compressive strains for all gage materials except Advance. Advance showed the worst variation; this may be caused as much by its high sensitivity to slight temperature fluctuations in the

liquid-hydrogen environment as by hysteresis. The Nichrome V gages showed an average hysteresis of less than 1 percent, while the stabilized Armour D showed an average of less than 2 percent for tensile and compressive strains.

Check of Variations in Gage Factor

The nominal gage factors for the stabilized Armour D and Nichrome V gages were 2.60 and 2.20, respectively. For either of these materials, only one source of Nichrome V supplied a gage factor tolerance; the tolerance was $\pm 4\frac{1}{2}$ percent. Room-temperature tensile tests of specimens, with both strain gages and mechanical extensometers mounted on them, showed, for 10 Nichrome V gages, an average variation of -2.3 percent with a maximum variation of -3.3 percent from the published gage factor. Similar tests on eight stabilized Armour D gages showed an average variation of +2.4 percent and a maximum variation of +4.7 percent. These results were obtained over a strain range of approximately 4000 microinches per inch. Because of nonlinearity effects with stabilized Armour D gages, the gage factors will depend on the strain range over which they are checked.

Measurement of Large Strains on Tensile Specimens

Some results of mounting stabilized Armour D and Nichrome V gages on tensile specimens and testing them to large strains in liquid hydrogen are shown in figure 8. All the stabilized Armour D gage elements were 0.250 inch wide and 0.125 inch long. Most of the gage failures in these tests were due to breaks in the elements; in some cases these were so fine that it was difficult to see them even with a microscope. There were few failures directly attributable to the cement bond; none occurred in any of the cases shown in figure 8. Even though the cement bond appeared generally satisfactory, some crazing, or hairline cracks, was evident after testing to high strains in liquid hydrogen. It is possible that breaks could be initiated in the foils where these fine cracks in the cement occur.

In figure 8(a) the two stabilized Armour D gages both failed above 8000 microinches per inch. There was some nonlinearity in both gages. This is not believed to be caused by bending because the extensometer curve is straight. On the whole, the gage readings agreed well with the extensometers.

The stabilized Armour D gages 4 and 3 of figure 8(b) failed above 8000 and 10,000 microinches per inch, respectively. Again, there is some nonlinearity in these gages, especially gage 3. For ordinary engineering purposes, the agreement between gages and extensometer is adequate.

Another pair of stabilized Armour D gages was tested to 10,000 microinches per inch without failure (fig. 8(c)). In contrast to the gages of figures 8(a) and (b), however, the drift was large. At 10,000 microinches per inch, the drift for both gages was nearly 1000 microinches per inch. It was not certain whether the gage or the cement caused the drift. This drift occurred over a

period of 2 hours. When a correction was made for the drift, there was reasonable agreement with the extensometer. Gage 6 showed good linearity, whereas, gage 5 did not.

The results of similar tensile tests in liquid hydrogen for Nichrome V gages are shown in figures 8(d) to (f). In figures 8(d) and (e), which represent gages from different manufacturers, the gages reached strains of 8000 and 11,000 microinches per inch, respectively, without any failure. There was good linearity and agreement with the extensometer in both cases. In figure 8(e) the drift at 11,000 microinches per inch was about 200 microinches per inch over a 2-hour period. Figure 8(f) shows the results from a pair of Nichrome V gages where the specimen was loaded continuously over a 1/2-hour period, and no correction for drift was attempted. Gage 5 showed fairly good linearity; the linearity of gage 6 was unsatisfactory. No extensometer was attached to this specimen. When the specimen failed after reaching a strain level about 13,000 microinches per inch, the cement bond showed some crazing.

SUMMARY OF RESULTS

Six types of electrical-resistance foil strain gages were investigated at cryogenic temperatures, and the following results were obtained:

1. Of the various types of strain gages tested, no one gage type was ideal in all respects. The two most promising gage materials were Nichrome V and stabilized Armour D. The former showed the better stability in strain sensitivity and somewhat better strength and linearity of gage output. When a gage is required for strain measurements on a structure at a constant cryogenic temperature, Nichrome V appears to be the best gage material to use. For measuring thermally induced strains across a transient temperature gradient in the cryogenic region, the stabilized Armour D gage can be used and corrected for the relatively small changes in resistance and strain sensitivity.
2. Stabilized Armour D showed a resistance change of less than 0.50 percent across the temperature region from room to liquid-helium temperature (7° R) and less than 0.25 percent from room to liquid-hydrogen temperature. The resistance of the Nichrome V gages decreased about 3 percent from room to liquid-helium temperature.
3. Nichrome V showed almost no change in gage factor from room to liquid-hydrogen temperature. No difference in results was found between Nichrome V gages obtained from two sources. Stabilized Armour D showed about a 4-percent decrease in gage factor for tensile strains and a $1\frac{1}{2}$ percent increase for compressive strains in a liquid-hydrogen environment up to a strain level of 2000 microinches per inch. No significant effect of gage-element size on the strain sensitivity was found.
4. Creep and zero-drift effects for stabilized Armour D and Nichrome V gages were small. At 2000 microinches per inch held for 1/2 hour, the maximum drift was only 16 microinches per inch. The drift tended to increase for the

stabilized Armour D gages as the gage-element size was decreased.

5. The hysteresis effect to 2000 microinches per inch in liquid hydrogen was within 2 percent for all the gages tested except Advance. It was less than 1 percent for the Nichrome V gages.

6. Stabilized Armour D gages were strained to over 8000 microinches per inch in liquid hydrogen before failure occurred. Some Nichrome V gages were strained to 13,000 microinches per inch without failure of either gages or the cement bond.

7. No change in either room-temperature resistance or strain sensitivity was found for any of the foil gages studied after immersion in the cryogenic fluids.

Lewis Research Center
National Aeronautics and Space Administration
Cleveland, Ohio, December 6, 1962

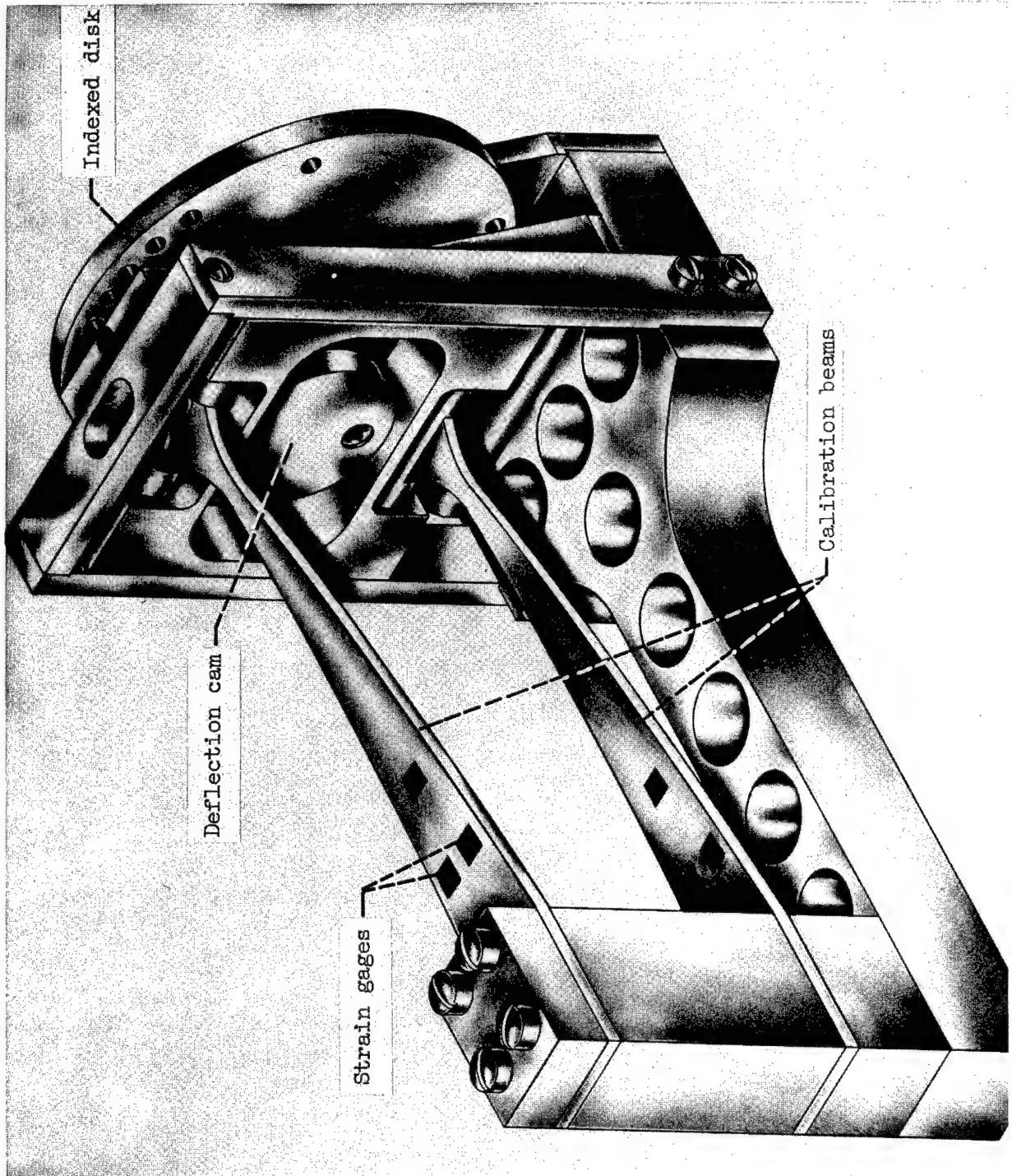
REFERENCES

1. Chiarito, Patrick J.: Strain Measurements at Cryogenic Temperatures. Vol. 7 of Advances in Cryogenic Eng., Plenum Press, 1962, pp. 433-439.
2. Calvert, Howard F., and Kemp, Richard H.: Determination of Pressure Vessel Strengths at -423° F as Influenced by Notches of Various Radii. Preprint 520B, SAE, 1962.
3. Hanson, Morgan P.: Smooth and Sharp-Notch Tensile Properties of Cold-Reduced AISI 301 and 304L Stainless-Steel Sheet at 75° , -320° , and -423° F. NASA TN D-592, 1961.

TABLE I. - RESULTS OF STRAIN SENSITIVITY TESTS WITH CALIBRATOR

Gage material	Gage-element size	Number of gages tested	Strain state	Strain-sensitivity ratio						
				Gage factor in liquid nitrogen/gage factor at room temperature	Gage factor in liquid hydrogen/gage factor at room temperature	Low	High	Average		
Nichrome V	0.18 .250	0.17 .125	10	{ Tension Compression	0.993 .996	1.029 1.009	1.004 1.002	0.989 .978	1.017 1.018	1.001 1.001
Karma	0.250	0.125	4	{ Tension Compression	1.074 1.068	1.085 1.085	1.080 1.077	1.087 1.073	1.099 1.101	1.092 1.090
Modified Karma	0.250	0.125	4	{ Tension Compression	1.048 1.056	1.072 1.067	1.060 1.062	1.056 1.051	1.070 1.083	1.063 1.068
Stabilized Armour D	0.125 .250 .500	0.0625 .125 .500	10	{ Tension Compression	0.935 0.978	1.005 1.056	0.961 1.012	0.945 0.996	0.974 1.034	0.963 1.015
Advance	0.250	0.125	4	{ Tension Compression	0.964 0.960	0.979 0.978	0.972 0.967	0.915 0.842	0.976 0.933	0.942 0.879
Nichrome V - platinum	0.39	0.50	a ₄	{ Tension Compression	1.057 1.051	1.057 1.057	1.057 1.054	1.067 1.061	1.062 1.061	1.062 1.061

aTwo failed.



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Figure 1. - Strain-gage calibrator.

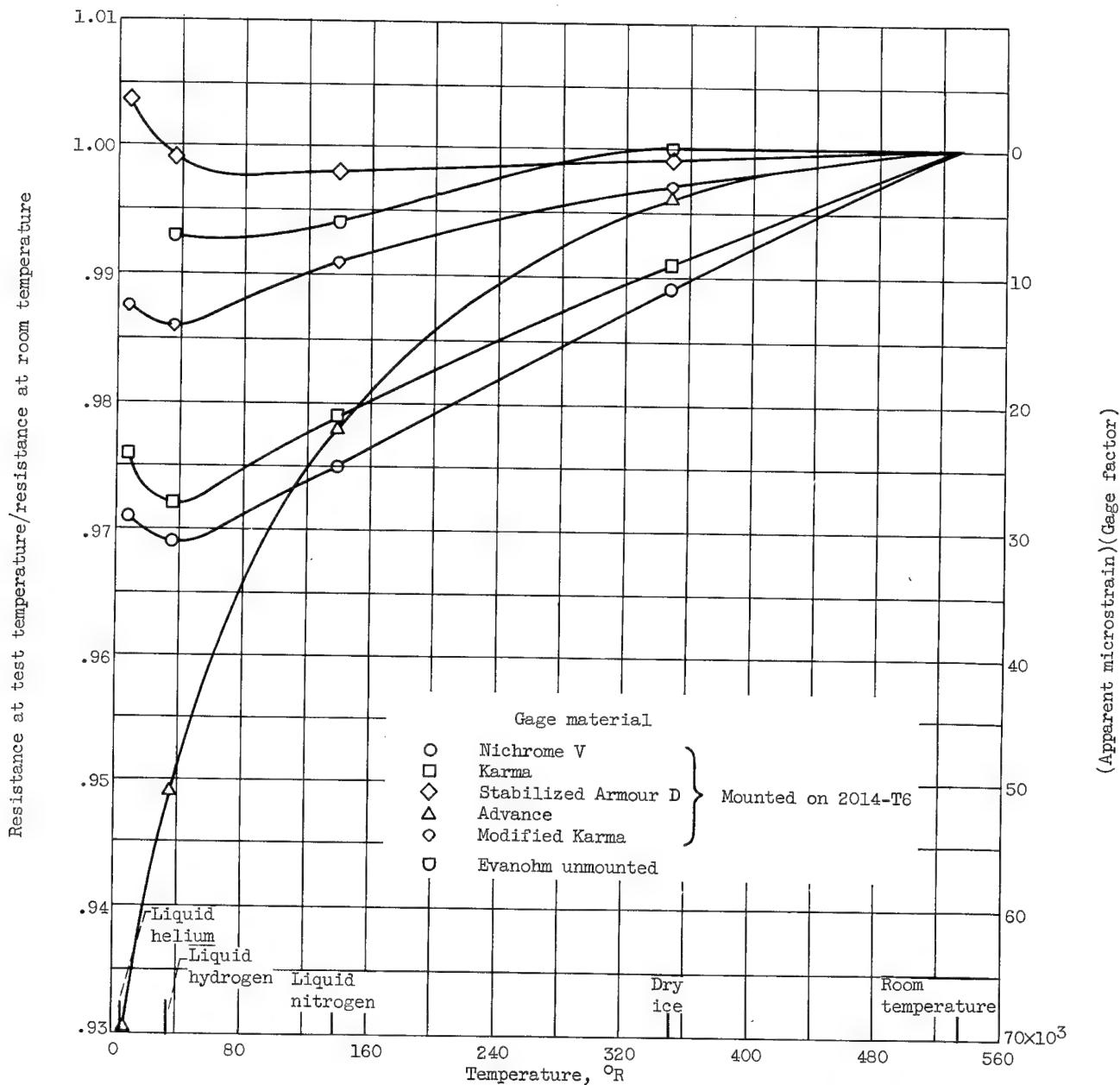


Figure 2. - Resistances of strain gages at various test temperatures compared with room-temperature resistances.

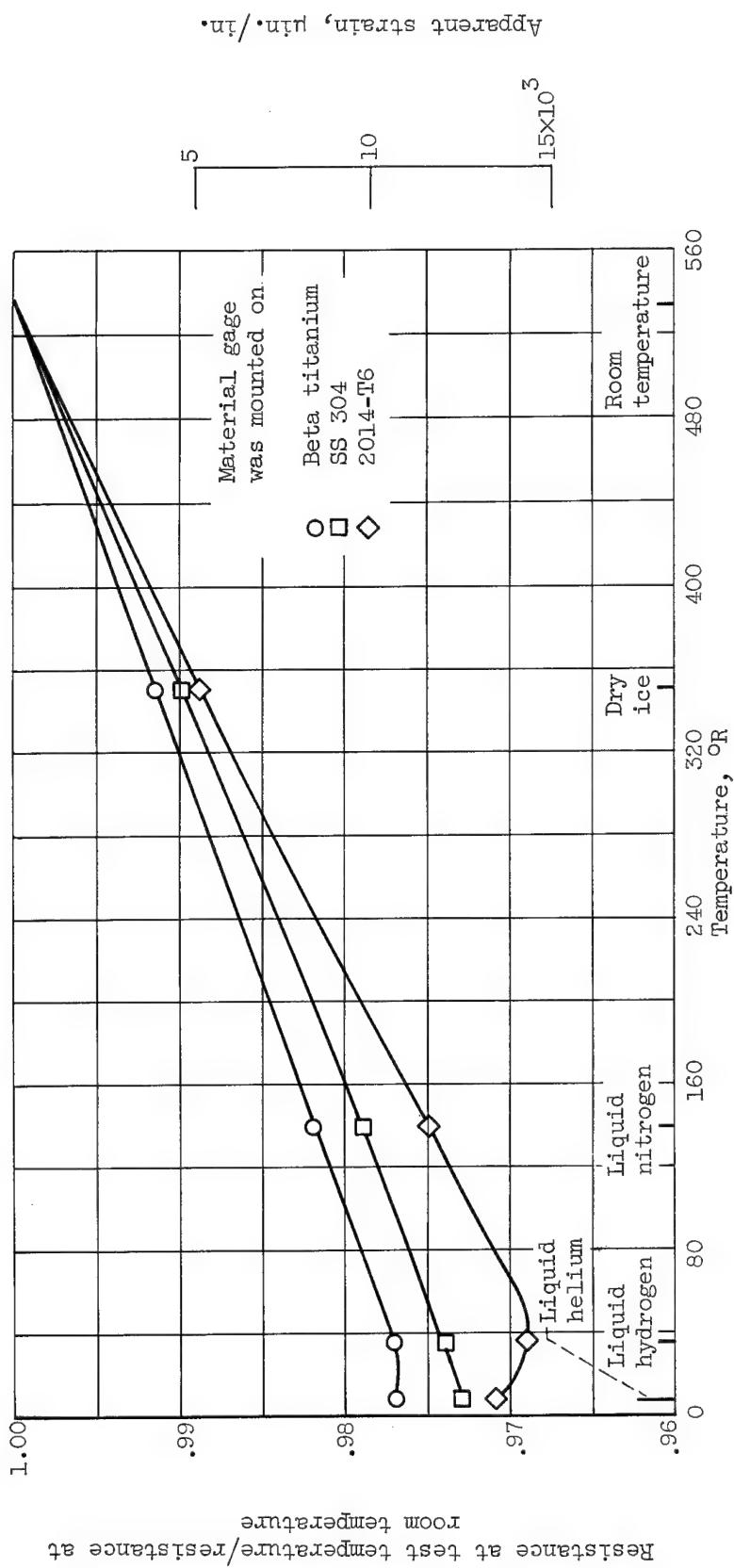


Figure 3. - Resistances of Nichrome V gages mounted on various materials compared with room-temperature resistances.

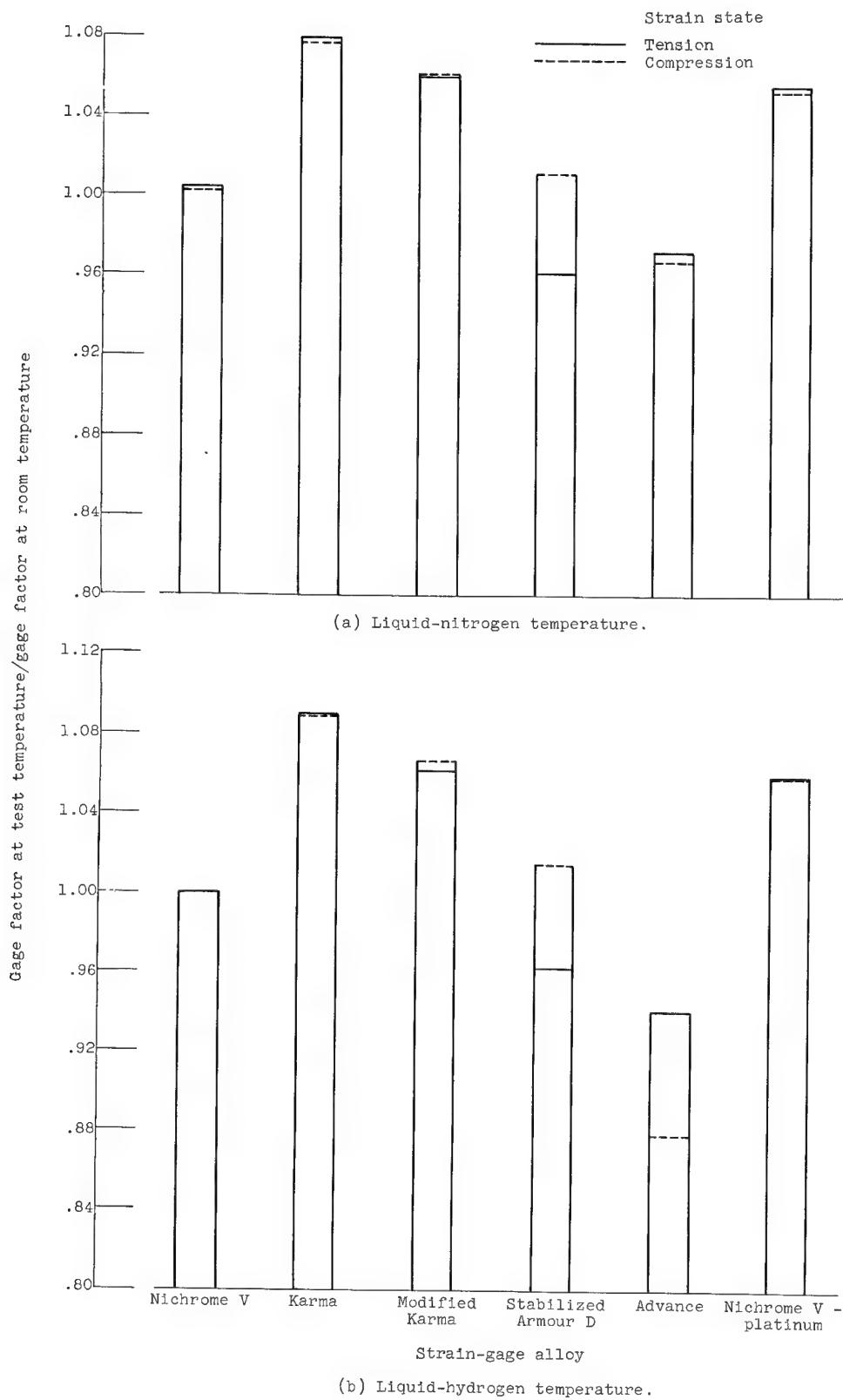
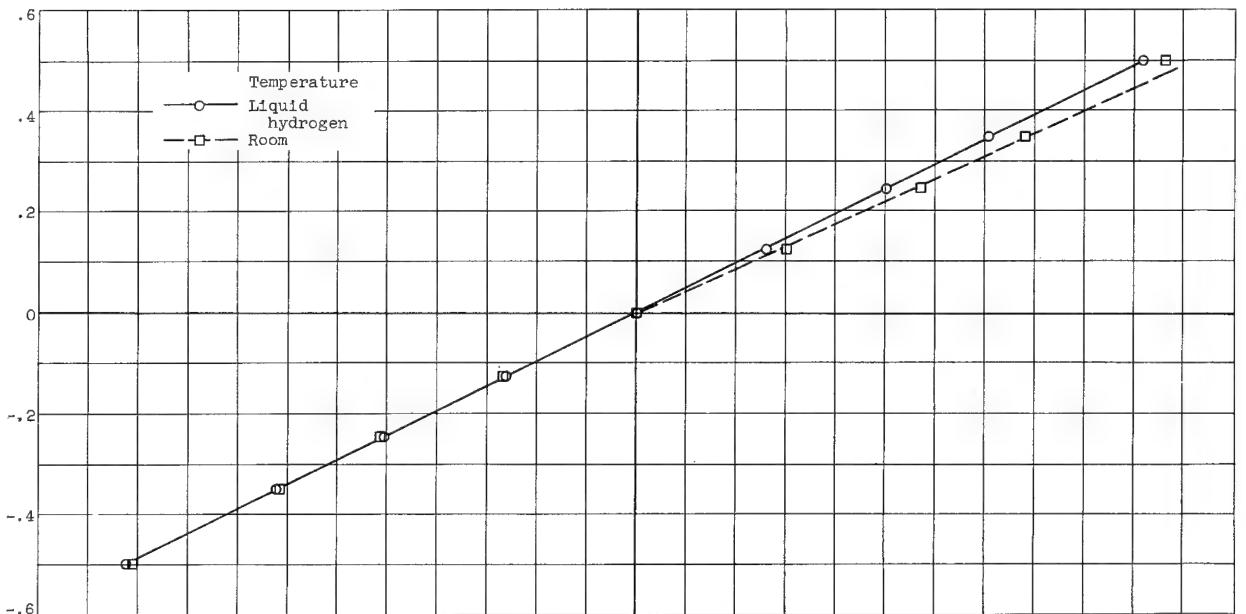
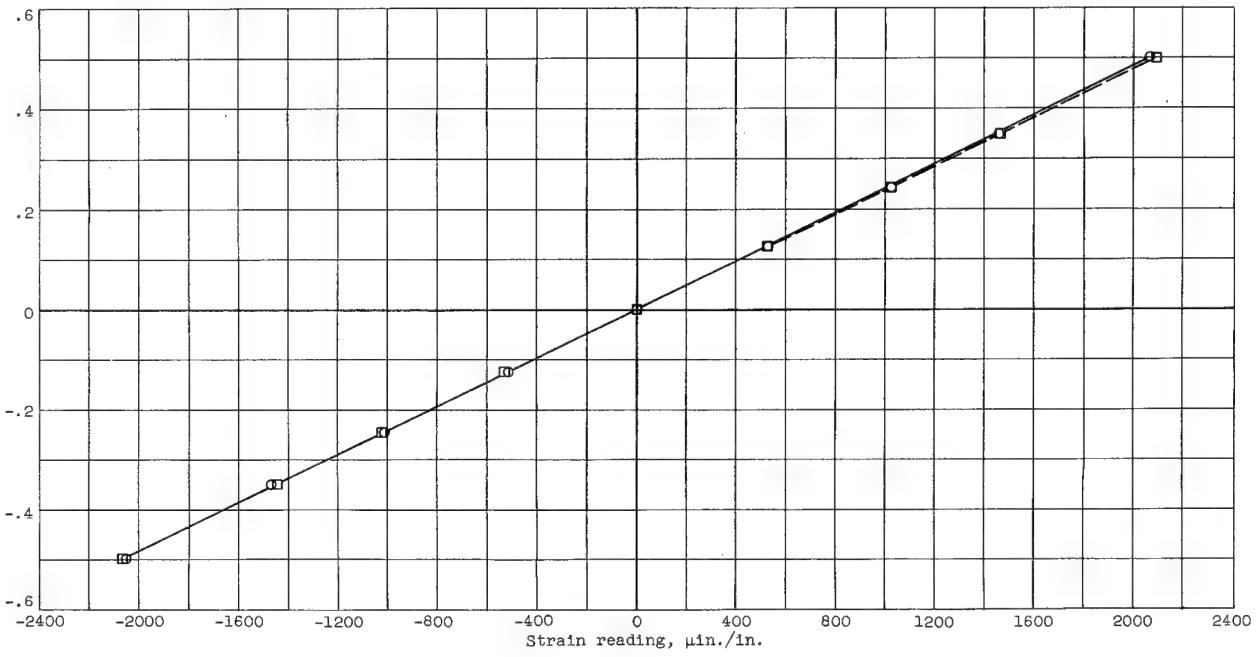


Figure 4. - Comparison of strain sensitivities at cryogenic and room temperatures for various strain gages.

Beam deflection, in.



(a) Stabilized Armour D gage.



(b) Nichrome V gage.

Figure 5. - Strain reading as function of deflection for strain gages on calibrator beam specimens.

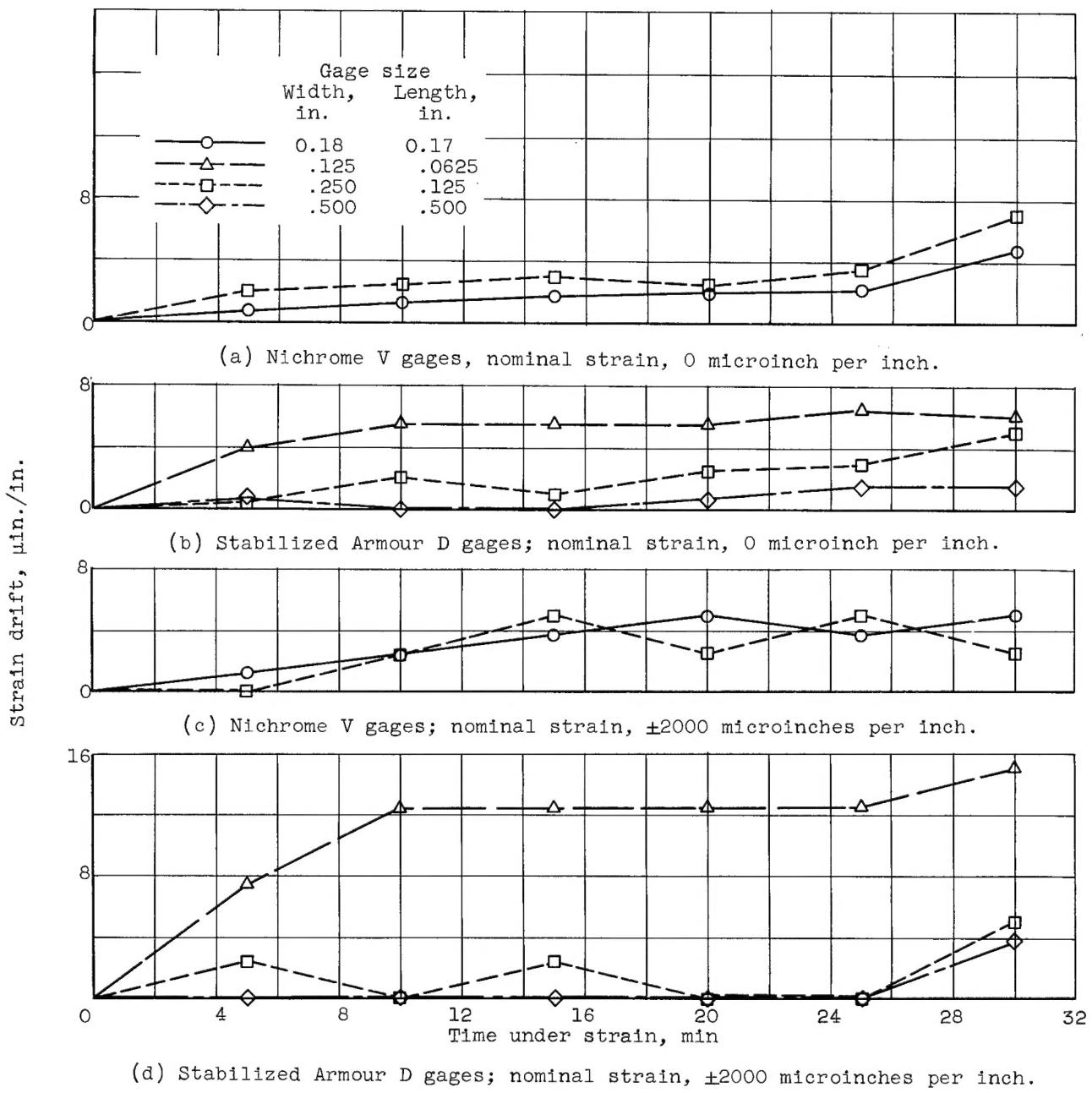


Figure 6. - Drift of strain gages at strain levels of 0 and ± 2000 microinches per inch in liquid hydrogen.

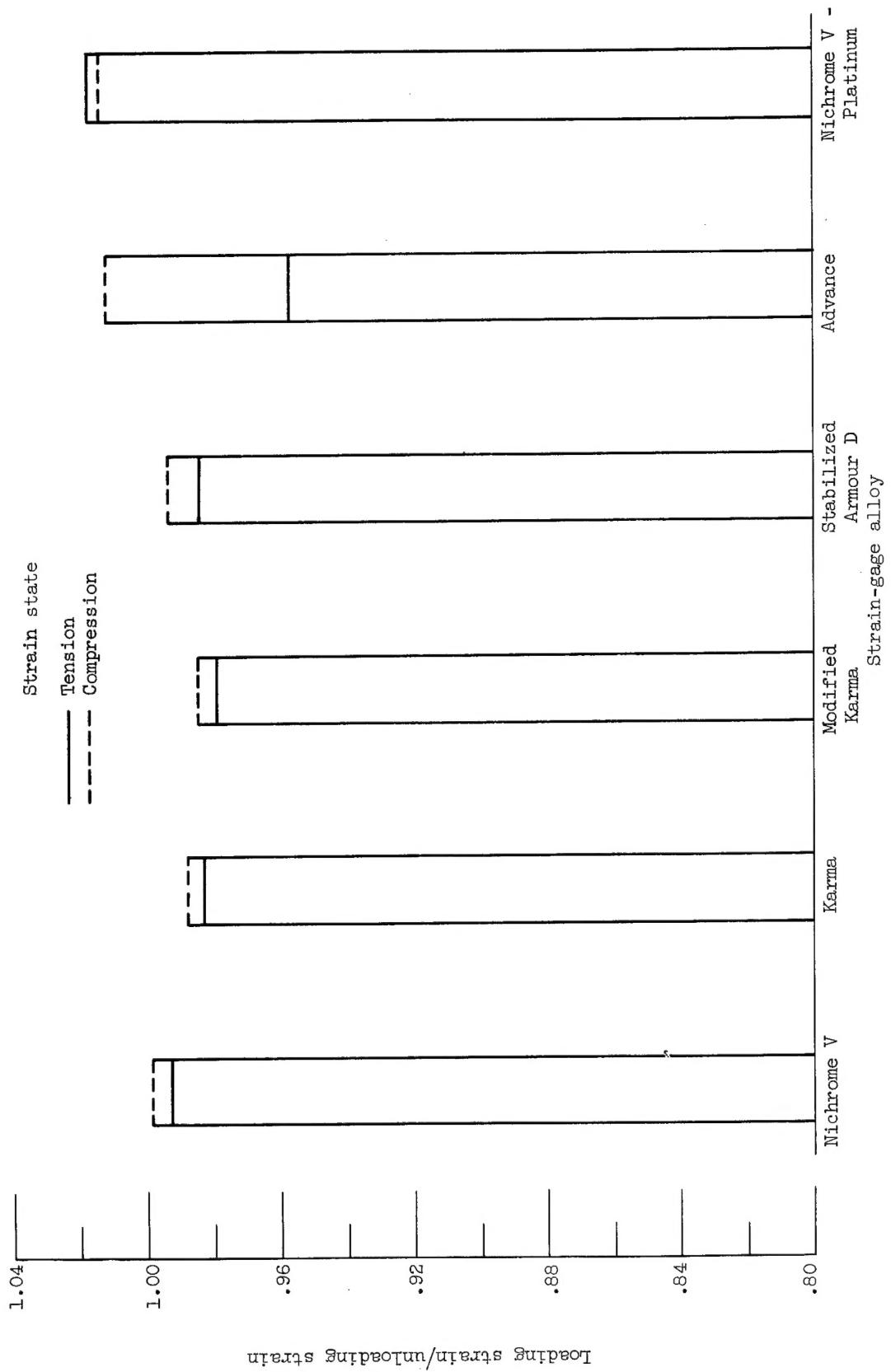
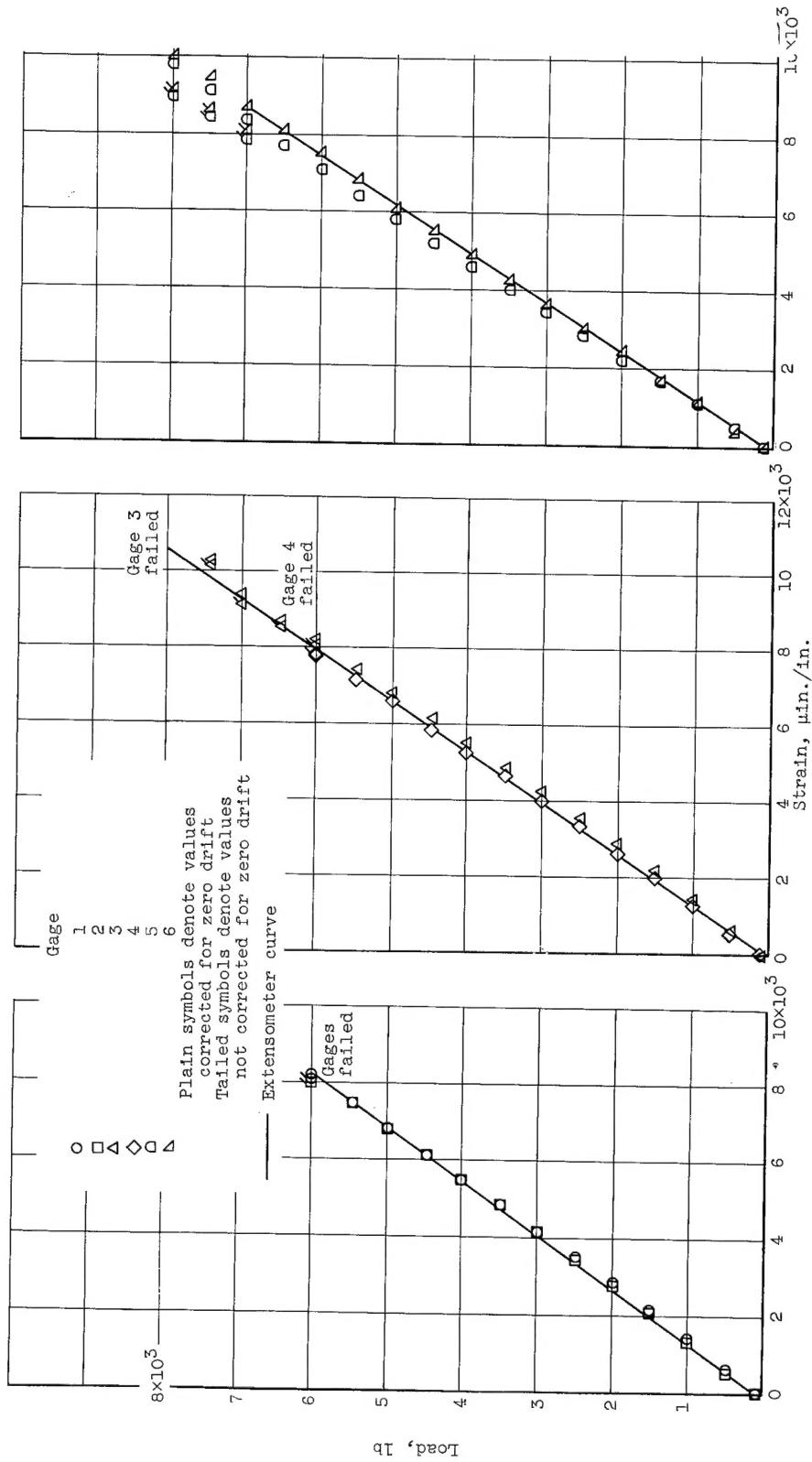
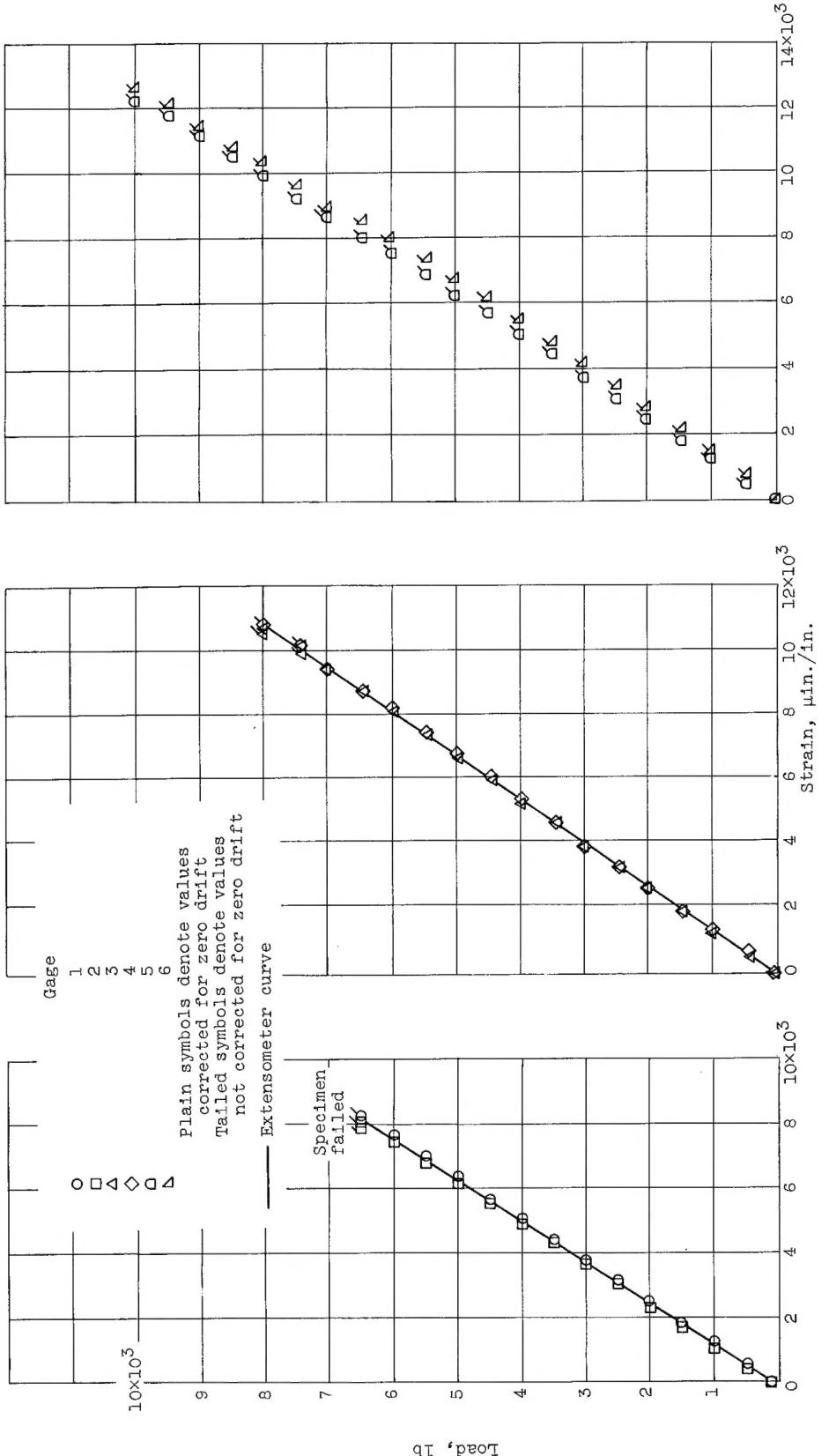


Figure 7. - Hysteresis effect from calibrator test for various strain gages in liquid hydrogen.



(a) Stabilized Armour D gages 1 and 2. (b) Stabilized Armour D gages 3 and 4. (c) Stabilized Armour D gages 5 and 6.
Figure 8. - Comparison of data from strain gages and extensometers mounted on beta titanium tensile specimens.



(f) Nichrome V gages 5 and 6. Gage size, 0.250 by 0.125 inch.

Figure 8. - Concluded. Comparison of data from strain gages and extensometers mounted on beta titanium tensile specimens.